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Performance Analysis of PSO-PD Controller in Controling the Rigid Gantry Crane System

Analisis Prestasi Kendali Pengendali PSO-PD dalam Pengendalian Sistem Gantry Crane Kaku

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Abstrak

Karya tulis ini membahas tentang algoritma particle swarm optimization (PSO) untuk mengoptimalkan penguat pengendali PD yang dinamakan pengendali PSO-PD. Efektivitas algoritma pengendali yang diusulkan diuji dengan menggunakan fungsi step dan dibandingkan dengan pengendali PD berbasis Zigler-Nichols (ZN-PD). Hasil simulasi yang didapatkan menunjukkan bahwa pengendali PSO-PD menghasilkan waktu naik dan waktu puncak yang lebih lambat dibandingkan dengan pengendali ZN-PD, tetapi memiliki waktu tunak yang lebih cepat dan nilai overshoot yang kecil di bawah trayektori yang didefinisikan.

Kata kunci: *Sistem gantry crane, PSO, Gain PD, Sudut ayunan*

Keywords:

Gantry crane system
PSO
PD gain
Swing angle

Abstract

This paper presents the particle swarm optimization (PSO) algorithm to optimize the gains of the PD controller to form what so-called the particle swarm optimization (PSO-PD) controller. The effectiveness of the proposed control algorithm is tested under constant step function and compared with Ziegler-Nichols (ZN-PD) controller. Simulation results show that proposed controller has slower rise time and peak time than ZN-PD controller as well as small overshoot under the predefined trajectories.

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INTRODUCTION

A crane called engineered a lifting system is a machine that can be used to lift or lower the load. Generally, this system is used in industry and is mainly used for lifting and transporting the heavy load to other places. The component of the crane which transports the load is called trolley. The load itself is called payload. One type of crane systems which is popular is gantry crane system. This type of crane has many variants such as ship to shore, full, rubber tyred, and workstation gantry crane.

In general, the task performed by a gantry crane is to pick the payload, raise it, move it to a target position, and lower it down on the crane framework. Because of traverse motion of the trolley during transport operations, the payload has the tendency to swing naturally. The swinging motion reduces the speed, accuracy, and safety requirements of crane operations. It lowers the speed of crane operations because the payload swing must be avoided before the payload can be safely lowered into specified position. Therefore, the swings make it difficult to perform alignment, fine position, or other accuracy driven tasks. Swing effect also causes safety problems to the crane framework. That's why control systems are needed to suppress the effects.

The control complexity of gantry crane challenges researchers because of the aforementioned problem. Various control algorithms have been proposed to address the problem. Anti-sway control for gantry cranes was proposed by Abe (2011) and Chen, Meng, and Zhang (2012) by using neural network method, Lin et al. (2016) and Lee et al. (2014) for direct adaptive fuzzy method, and M. J. Maghsoudi et al. (2015), Mohammad Javad Maghsoudi et al. (2016), and Mar et al. (2017) for input-shaping method. Priority-based fitness binary particle swarm optimization (PFBSO) was introduced by Kennedy and Eberhart (Jaafar et al. 2014). The rest can be referred to references (Sorensen, Singhose, and Dickerson 2007; Jaafar et al. 2013; Jaafar et al. 2014; Diep and Khoa 2014; Ileš et al. 2015; Alhassan et al. 2015; Hussien et al. 2016a; Hussien et al. 2016b; He and Ge 2016).

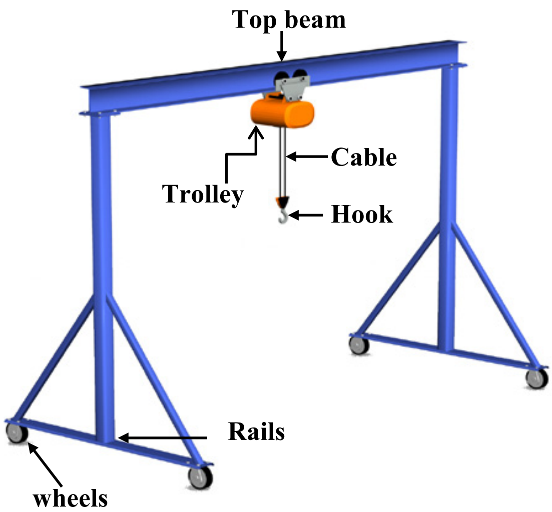


Figure 1. Gantry crane system *("Hoosier Crane Service Company" 2017)*

In this paper, particle swarm optimization (PSO) is proposed as an optimizer for tuning the optimal gains of PD controller. This is intended to improve the control capacity of the PD controller. It is then applied for control position of the rigid gantry crane system as well as reduction of swinging of the payload. The comparison is performed by taking Ziegler-Nichols (ZN) based PD controller as a benchmark.

This paper is organized as follows: Section 1 presents the introduction. Section 2 gives the derivation of the mathematical model of rigid gantry crane system. Section 3 depicts a block diagram of a PD controller (PDC) for controlling the underlying system. Section 4 describes the optimization of PD controller via PSO algorithm. Section 5 displays and discusses the control results. Section 6 is the conclusion of this paper.

MODELING OF RIGID GANTRY CRANE

A schematic of gantry crane is shown in Fig. 2. The configuration models of this gantry crane consist of mass of trolley (m_T), mass payload (m_P), and hoist cable (ℓ_P).The payload has one swing angle concerning the inference frame: θ is denoted as angle between the x_T-axis and $x_T y_T$-plane. The payload swings either in small or large swing angles. Friction between trolley and the top beam of crane framework and dynamics of hoist cable and drum in hoist system and hoist drive mechanism are not considered. The structure is treated as a rigid body.

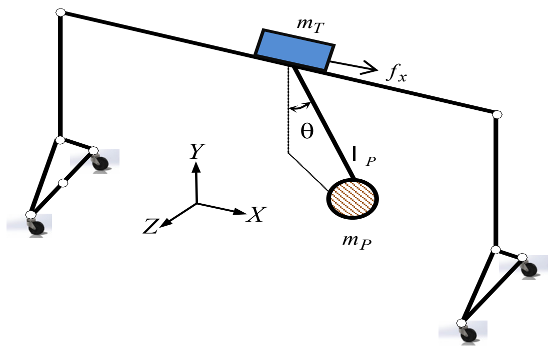


Figure 2. Schematic of gantry crane system

The general equations of gantry crane system have been derived in references (Abe 2011; Zhang, Cheng, and Cai 2014; Singhose et al. 2000). However, it is revisited here and rewritten as follows:

$$(m_T + m_p)x_T + c_x x_T + m_p \ell_P(\theta\cos\theta - \theta^2\sin\theta) = f_x, \quad (1)$$

$$\frac{x_T}{\ell_P}\cos\theta + \theta + \frac{g}{\ell_P}\sin\theta = 0. \quad (2)$$

Equation (1) is expanded by considering the dynamic of trolley motor. The input f_x in Eq. (1) can be rewritten by considering the trolley motor.

$$f_x = \frac{T_x}{r_p} z = \frac{K_T z}{R_T r_p} u_T - \frac{K_T^2 z}{R_T r_p^2} x \quad (3)$$

$$(m_T + m_p)x_T + c_x x_T + m_p \ell_P(\theta\cos\theta - \theta^2\sin\theta) = \frac{K_T z}{R_T r_p} u_T - \frac{K_T^2 z}{R_T r_p^2} x_T. \quad (4)$$

Parameters in Eq. (4) contain terms as follows: K_T, R_T, u_T are torque constant, motor resistance and input voltage respectively, while z, r_p are gear ratio and radius of motor pulley, respectively.

CLOSED-LOOP CONTROL SYSTEM WITH PSO-PD CONTROLLER

A typical block diagram of a PDC which is combined with PSO algorithm for controlling the rigid gantry crane system is shown in Fig 3. The figure shows that the system is classified as an under-actuated system and SIMO system (single input multi-output). Error and error derivative of trolley position becomes the first input for the controller while the error and error derivative of payload swing becomes the second input. Thus, both are combined and used to generate the proportional and derivative signals, which is weighted, summed to form the control signal u_T, and applied to the underlying system.

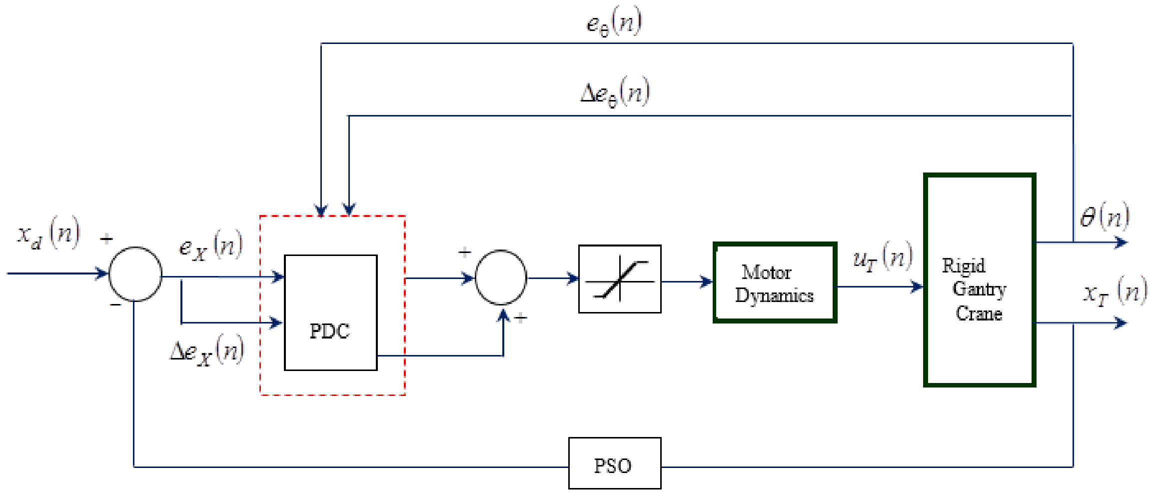


Figure 3. Diagram block of PSO-PD controller for rigid gantry crane system

It should be noted that integral action is not necessarily due to the *windup* (presence of integral, reset) leading to significant overshoots. Thus, PD controller is suitable for controlling the system. The gains are named as proportional (K_p) and derivative (K_d). Both gains are tuned to match the system input (reference) and the system output (response) by giving the feedback in terms of control action u_T. By referring to the diagram block depicted in Fig. 3, the output of PD controller can be calculated using Eq. (5) below,

$$u(n) = K_p\{e_X(n) + e_\theta(n)\} + K_d\{\Delta e_X(n) + \Delta e_\theta(n)\} \quad (5)$$

Eq. (5) contains terms as follows: e_X, Δe_X, e_θ, Δe_θ, which are error and error derivative of trolley position and so are payload swing, respectively. The gains of trolley position and swinging of the payload in Eq. (5) are similarly defined so that controllers for trolley and payload have similar gains. Both gains can be defined separately, however, if it is intended to be similar so as to make the optimization process efficient. The gains in Eq. (5) are significantly affected in the closed-loop response under any types of signal input. Suboptimal values of the gains lead to the system become unstable, high overshoot, and large steady-state error. Hence, particle swarm optimization algorithm are proposed to optimize the gains of PDC.

OPTIMIZATION OF PD CONTROLLER VIA PSO ALGORITHM

PDC gains recalled as $\{K_p, K_d\}$ are initialized randomly and called as particles in PSO-PD controller. These particles have initial velocity and position and are evaluated by using cost function in Eq. (6).

$$SSE = \sum_{n=1}^{N} \left(x_T(n) - \hat{x}_T(n) \right) \quad (6)$$

Terms in Eq. (6) are as follows: N is the number of data, $x_T(n)$ is the actual trolley position, while $\hat{x}_T(n)$ is the calculated trolley position. Particles with the highest cost value ares stored as p_{best}, whereas the particles with the lowest cost value are taken as g_{best}. The value p_{best} indicates the current closest particle's position to the target. The goal of the PSO method is to accelerate each particle in the g_{best} toward p_{best} in each iteration by increasing its velocity. In order to achieve this goal, the velocity and position of each particle must be updated. The updating of the particle's velocity and position can utilize equations as shown in Eqs. (7) and (8) (Yazid et al. 2015a; Yazid et al. 2015b)a static analysis is still central to a preliminary determination of the dimensions required. However, to bring the results of these calculations closer to reality, different quasi-static procedures are introduced. These procedures take account of various dynamic effects by means of appropriate coefficients. In this paper, a new procedure is proposed for determining the maximum horizontal inertial forces in a radial direction that are acting on a load suspended from the jib during a crane's slewing motion. Based on a previously developed and verified mathematical model of a general-type slewing crane, we undertook the following. Firstly, we verified that the horizontal inertial forces in the radial direction are of no less importance (no smaller in terms of their magnitude,

$$v_{ij} = c_0 v_{ij} + c_1 r_1 \left(p_{best_{ij}} - x_{ij}\right) + c_2 r_2 \left(g_{best_i} - x_{ij}\right) \quad (7)$$

$$x_{ij} = x_{ij} + v_{ij} \quad (8)$$

Eqs. (7) and (8) contain parameters are as follows: x_{ij} and v_{ij} denote the *i*-th position and velocity components of the *j*-th particle, respectively. Index *i* is the number of particle, while *j* is the population size. Eq. (7) contains three constants c_0, c_1 and c_2 which are set by the designer. Constant c_0 is the inertia weight, which balances the local and the global searches, c_1 is the cognition acceleration and c_2 is the social acceleration constant. The terms r_1 and r_2 are two random numbers uniformly selected from the interval $[0,1]$. Eqs. (7) and (8) also suggest that the PSO method is not a complicated optimization technique as it only involves two updating mechanisms.

RESULT AND DISCUSSION

Control simulation is started by substituting the basic parameters of gantry crane system in Table 1 and motors into Eqs. (2) and (4). Both equations are solved using fourth-order Rung-Kutta with sampling time of 0.01 s and time duration of 180 s, which are performed simultaneously in Matlab. Parameters of PSO algorithm as optimizer are shown in Table 2, where interval for searching space is $0 \le x \le 200$ for $\{K_p, K_d\}$.

Table 1. Gantry crane parameters

Parameters	
Trolley mass, m_T	50 kg
Payload mass, m_p	1200 kg
Cable length, l_p Gravitational acceleration, g	1 m $9.81 m/s^2$
Initial conditions, $\theta_o, \theta_0, \theta_0$	$0^o, 0, 0$

Table 2. Parameters of PSO algorithm

PSO			
Number of iterations	50	Inertia weight, c_0	2
Number of particles	50	Cognition acceleration, c_1	2
Number of optimized parameters	2	Social acceleration, c_2	1

Performance of proposed controller is tested under constant step function, where the crane is commanded to track a position in $x \to 12\, m$. Control performances are assessed in time domain in terms of rise time, settling time, overshoot, and peak time. Time domain responses obtained from ZN-PD and PSO-PD controllers are then compared one to another. The control results are are shown in Fig. 4. As can be seen, the crane is able to track the commanded position. The ZN-PD and PSO-PD controllers have successfully stabilized the trolley position with respect to time. The error of trolley position decays to zero as confirmed by Fig. 5.

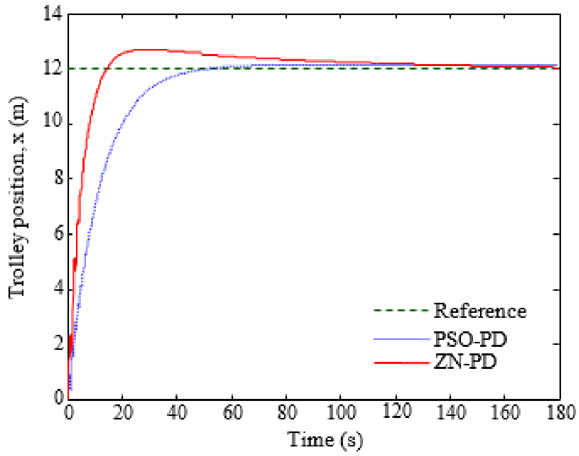


Figure 4. Trolley position

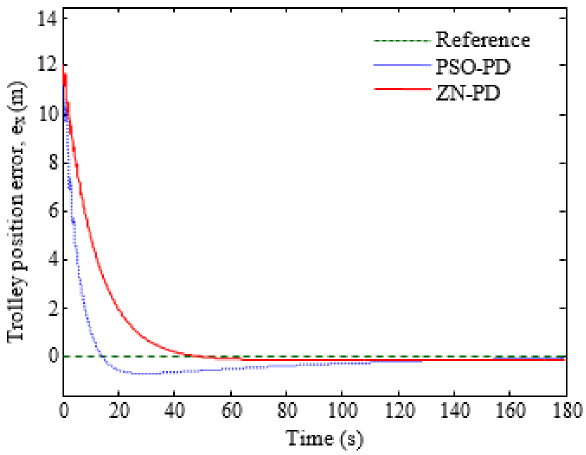


Figure 5. Error of trolley position

Table 3. PSO-PD's performances under step function

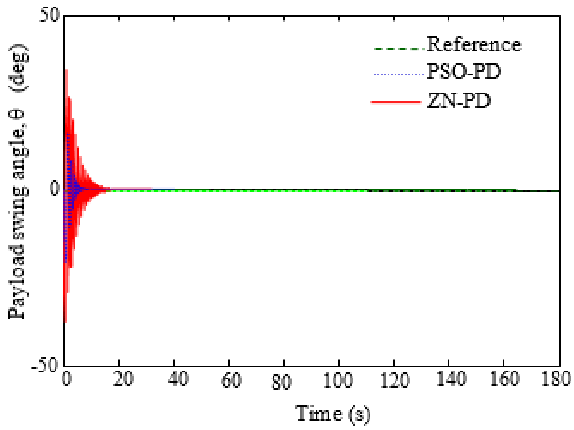
Performance	ZN-PD	PSO-PD
Rise time	8.31	24.77
Settling time	58.44	44.07
Overshoot	4.58	0.04
Peak time	24.3	108.2

If Figs. 4 and 5 are observed, then each controller seems to have different performances in tracking the commanded position. The PSO-PD controller has slow rise time and peak time compared to ZN-PD controller. The fast rise time and peak time of ZN-PD controller create overshoot until it reaches its settling time. This is contrast with PSO-PD controller, where the slow rise time and peak time lead to small overshoot so that settling time can be achieved faster than ZN-PD controller. Performance comparisons are displayed in Table 3.

The gains of PD controller optimized from PSO algorithm are tabulated in Table 4. It is seen that the gain of K_p is lower than initial value (before optimization) while the gain of K_d is higher than initial value (after optimization).

Table 4. Optimal gains of PD controller under step function

Gains	ZN-PD	PSO-PD
	Nominal	Optimized
K_p	1.36	0.07
K_d	56.85	29.32



(a)

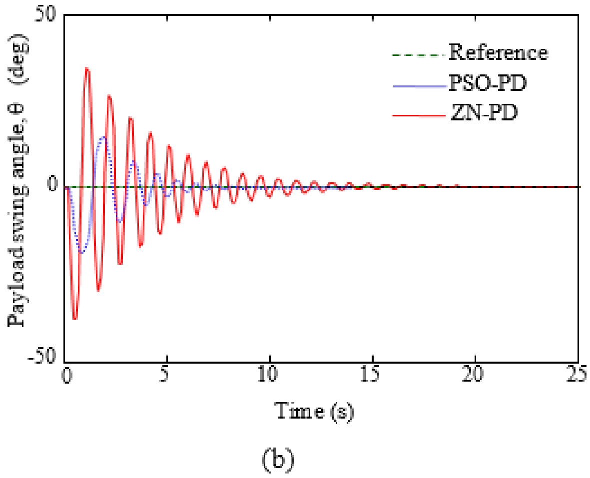


Figure 6. Payload swing angle under for step function (a) time window 0-180 s (b) time window 0-25 s

Further, optimized gains of PSO-PD controller seems lower than nominal gains of ZN-PD controller. This is to be expected and it explains why the PSO-PD controller has the low rise time and peak time, fast settling time as well as small overshoot. Because it is known that the function of gain K_p is to increase the rise time of the system response and the function of gain K_d is to reduce the oscillation.

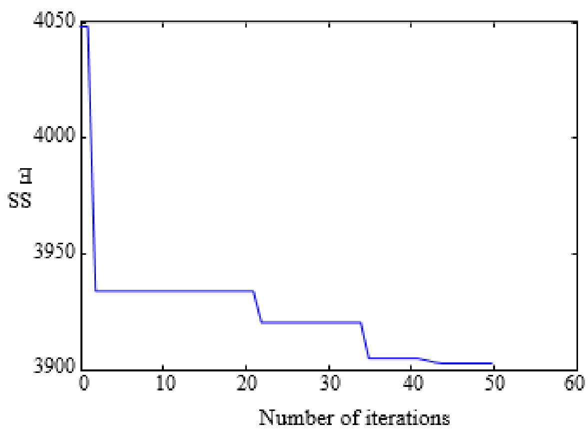


Figure 7. Cost function for step function with respect to number of iterations

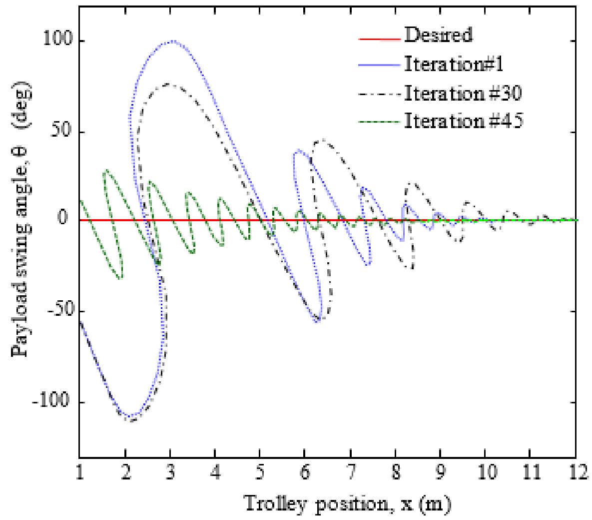


Figure 8. Performance of particle 1 in the optimization process

Control performance in Figs. 4-5 is elaborated by Fig. 6. The figure shows the consequent of fast rise time and peak time of ZN-PD controller. The faster the trolley reaches the target position, the bigger the swing angle of payload occurs. Large swing angle of payload of ZN-PD controller in Fig. 6 is the consequent of using full nonlinear dynamic model in Eqs. (9) and (11). At this point, control designer can choose whether the trolley moves fast with large swing angle as expense or reasonable speed of trolley with no overshoot. The latter is favorable since it is required for safety reason in crane operation. Hence, all results confirm that the PSO-PD controller outperforms the ZN-PD controller.

In optimizing the gains, PD controller optimized by PSO algorithm produces a cost function as shown in Fig. 7. It displays the cost function with respect to the number of iterations. As observed, the cost exhibits a gradual convergence and seems like a ladder function as the number of iteration increases. However, the cost function starts to converge after the-45th iteration and it is steady to a certain value.

Performance of the particle 1 in the optimization process of PSO algorithm is selected and presented in Fig. 8. It can be observed that as the iteration number increases, the particle moves to the target. It leads to a condition that the crane has moved to the commanded position while at the same time, the swinging of the payload has been suppressed to a minimal angle.

CONCLUSION

In this paper, a controller namely the PSO-PD is proposed to control the rigid gantry crane system. The results show that the proposed controller can improve the performance of closed-loop control system under a constant step function. The PSO-PD controller surpasses the ZN-PD controller, where the earlier has slower rise time and peak time, but faster settling time than the latter as well as small overshoot with respect to the predefined trajectories. The cost function generated from the PSO-PD controller seems like a ladder function. The proposed controllers can easily be applied to PID controller, where the gain K_i is included.

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REFERENCES

Abe, Akira. 2011. "Anti-Sway Control for Overhead Cranes Using Neural Network." *International Journal of Innovative Computing, Information and Control* 7: 4251–4562. http://www.ijicic.org/ijicic-10-06016.pdf.

Alhassan, Ahmad Bala, Bashir Bala Muhammad, Kumeresan A Danapalasingam, and Yahaya Md Sam. 2015. "Optimal analysis and control of 2D nonlinear gantry crane system." In *2015 International Conference on Smart Sensors and Application (ICSSA)*, 30–35. IEEE. doi:10.1109/ICSSA.2015.7322505.

Chen, Zhi-mei, Wen-jun Meng, and Jing-gang Zhang. 2012. "Intelligent anti-swing control for bridge crane." *Journal of Central South University* 19 (10): 2774–81. doi:10.1007/s11771-012-1341-6.

Diep, D V, and V V Khoa. 2014. "PID-Controllers Tuning Optimization with PSO Algorithm for Nonlinear Gantry Crane System." *International Journal of Engineering and Computer Science (IJECS)* 3 (6): 6631–35. http://www.ijecs.in/index.php/archive/117-volume-3-issue-6-june-2014.

He, Wei, and Shuzhi Sam Ge. 2016. "Cooperative control of a nonuniform gantry crane with constrained tension." *Automatica* 66 (January). Elsevier Ltd: 146–54. doi:10.1016/j.automatica.2015.12.026.

"Hoosier Crane Service Company." 2017. Diakses Maret 22. https://www.hoosiercrane.com.

Hussien, S Y S, R Ghazali, H I Jaafar, and C C Soon. 2016a. "An Experimental of 3D Gantry Crane System in Motion Control by PID and PD Controller via PFPSO Optimization." *Journal of Telecommunication, Electronic and Computer Engineering* 8 (7): 133–37.

———. 2016b. "Analysis of 3D Gantry Crane System by PID and VSC for Positioning Trolley and Oscillation Reduction." *Journal of Telecommunication, Electronic and Computer Engineering* 8 (7): 139–43.

Ileš, Šandor, Mircea Lazar, Fetah Kolonić, and Jadranko Matuško. 2015. "Stabilizing Model Predictive Control of a Gantry Crane Based on Flexible Set-Membership Constraints." *IFAC-PapersOnLine* 48 (23): 248–53. doi:10.1016/j.ifacol.2015.11.291.

Jaafar, Hazriq Izzuan, Zaharuddin Mohamed, Amar Faiz Zainal Abidin, Zamani Md Sani, Jasrul Jamani Jamian, and Anuar Mohamed Kassim. 2014. "Performance Analysis for a Gantry Crane System (GCS) Using Priority-Based Fitness Scheme in Binary Particle Swarm Optimization." *Advanced Materials Research* 903 (Februari): 285–90. doi:10.4028/www.scientific.net/AMR.903.285.

Jaafar, Hazriq Izzuan, Z Mohamed, J.J. Jamian, Amar Faiz Zainal Abidin, Anuar Mohamed Kassim, and Z Ab Ghani. 2013. "Dynamic Behaviour of a Nonlinear Gantry Crane System." *Procedia Technology* 11 (Iceei). Elsevier B.V.: 419–25. doi:10.1016/j.protcy.2013.12.211.

Lee, Lun-Hui, Chung-Hao Huang, Sung-Chih Ku, Zhi-Heng Yang, and Cheng-Yuan Chang. 2014. "Efficient Visual Feedback Method to Control a Three-Dimensional Overhead Crane." *IEEE Transactions on Industrial Electronics* 61 (8): 4073–83. doi:10.1109/TIE.2013.2286565.

Lin, Tsung-Chih, Yu-Chen Lin, Majid Moradi Zirkohi, and Hsi-Chun Huang. 2016. "Direct Adaptive Fuzzy Moving Sliding Mode Proportional Integral Tracking Control of a Three-Dimensional Overhead Crane." *Journal of Dynamic Systems, Measurement, and Control* 138 (10): 101001. doi:10.1115/1.4033414.

Maghsoudi, M. J., Z. Mohamed, MO Tokhi, AR Husain, and MS Zainal Abidin. 2015. "Control of a gantry crane using input-shaping schemes with distributed delay." *Transactions of the Institute of Measurement and Control*, Oktober. doi:10.1177/0142331215607615.

Maghsoudi, Mohammad Javad, Z Mohamed, A.R. Husain, and M.O. Tokhi. 2016. "An optimal performance control scheme for a 3D crane." *Mechanical Systems and Signal Processing* 66–67 (Januari). Elsevier: 756–68. doi:10.1016/j.ymssp.2015.05.020.

Mar, Robert, Anurag Goyal, Vinh Nguyen, Tianle Yang, and William Singhose. 2017. "Combined input shaping and feedback control for double-pendulum systems." *Mechanical Systems and Signal Processing* 85 (Februari). Elsevier: 267–77. doi:10.1016/j.ymssp.2016.08.012.

Singhose, William, Lisa Porter, Michael Kenison, and Eric Kriikku. 2000. "Effects of hoisting on the input shaping control of gantry cranes." *Control Engineering Practice* 8 (10): 1159–65. doi:10.1016/S0967-0661(00)00054-X.

Sorensen, Khalid L, William Singhose, and Stephen Dickerson. 2007. "A controller enabling precise positioning and sway reduction in bridge and gantry cranes." *Control Engineering Practice* 15(7): 825–37. doi:10.1016/j.conengprac.2006.03.005.

Yazid, Edwar, Mohd Shahir Liew, Setyamartana Parman, and Velluruzhatil John Kurian. 2015a. "Identification of slow drift motions of a truss spar platform using parametric Volterra model."*Ocean Engineering* 109: 654–668. doi:10.1016/j.oceaneng.2015.09.055.

———. 2015b. "Improving the modeling capacity of Volterra model using evolutionary computing methods based on Kalman moother adaptive filter." *Applied Soft Computing* 35: 695–707. doi:10.1016/j.asoc.2015.05.046.

Zhang, Da Peng, Wen Ming Cheng, and Kun Cai. 2014. "Study on Prediction Deflection of at the Girder Midspan of Large Tonnage Gantry Crane Rigid Legs." *Applied Mechanics and Materials* 628 (September): 214–18. doi:10.4028/www.scientific.net/AMM.628.21.